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PROBLEM AND A WATER-QUALITY
INVENTORY OF THE MONTANA PLAINS

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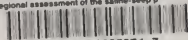
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by

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and

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with a section on

ALGAL POPULATIONS IN SEEP-AFFECTED WATER, WITH AN
EMPHASIS ON SALINITY INDICATORS AND POTENTIALLY TOXIC SPECIES

by

L. L. Bahls and P. A. Bahls

FINAL REPORT
Project No. A-076-MONT
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Montana Water Resources Research Center
Montana State University
Bozeman, Montana 59717

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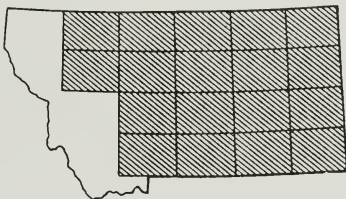
REGIONAL ASSESSMENT OF THE SALINE-SEEP PROBLEM AND A WATER-QUALITY INVENTORY OF THE MONTANA PLAINS

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MONTANA COLLEGE OF MINERAL SCIENCE AND TECHNOLOGY
Butte, Montana

CONTENTS

| | Page |
|--|------|
| Abstract | i |
| Introduction | 1 |
| Method of Study | 1 |
| Project Objectives | 3 |
| Comparison of Saline-Seep Formation in Great Plains Region | 4 |
| Regional Extent of Saline-Seep Development in Montana | 9 |
| Algal Survey of Selected Streams and Reservoirs | 11 |
| Water Quality and Specific Conductance Survey of the Montana Plains | 13 |
| Conclusions | 17 |
| Recommendations | 18 |
| Literature Cited | 19 |
| Appendix A--Site Location System | 21 |
| Appendix B--Legend for map symbols and aquifer code | 23 |

ABSTRACT

The regional water-quality inventory of the Montana Plains suggests that significant water-quality deterioration has occurred in the glaciated portion of Montana where dryland farming has been practiced for many years. Several non-glaciated areas where saline seep is spreading rapidly are Judith Basin, Fergus, and Stillwater counties--also in areas of dryland farming.

The regional survey of wells, springs, streams, and reservoirs was conducted over a 42-county area encompassing roughly 118,000 square miles. More than 2,800 sites were evaluated in the field and 452 water samples were collected, of which 247 were analysed for trace elements. Specific conductance of the water ranged from 1,000 to 10,000 micromhos per centimeter at 64 percent of the sites. Conductivities were considerably higher in wells penetrating Cretaceous marine aquifers than in the non-marine late Cretaceous and Tertiary aquifers. Significant concentrations of trace elements, particularly selenium and boron, were found in many of the ground-water samples. Of the 160 samples analysed for selenium, more than 30 percent had concentrations greater than 10 micrograms per liter; some had values as high as 1,800 micrograms per liter.

The aerial reconnaissance survey indicated that the previous estimate of 200,000 acres of saline seep in Montana is somewhat low. The survey showed that there were considerably more affected acres in northern and central Montana than formerly thought, and, conversely, that southern and eastern Montana contained fewer seep acres.

A survey of 100 algal specimens collected from selected stream and reservoirs revealed that 25 percent of the water samples contained potentially toxic blue-green algae that could be responsible for some of the reported livestock kills.

KEY WORDS

Water quality, saline seep, ground water, local flow systems, hydrogeology, saline soils, summer fallow, pollution, selenium.

INTRODUCTION

The widespread occurrence and rapid growth of saline seep on or adjacent to cultivated drylands has become one of the most serious conservation problems in the Great Plains Region (7). Dryland salinity, hardly recognized 30 years ago, has now taken roughly two million acres out of production in the plains region--Montana, North and South Dakota, Alberta, Saskatchewan, and Manitoba (13).

Since 1969, the Montana Bureau of Mines and Geology in cooperation with numerous local, state, and federal organizations has been investigating the saline-seep problem. The Bureau has emphasized and examined the hydrological, geological, and water quality aspects of the problem (1, 9). In 1974, available analyses of water collected near Fort Benton and Sidney, Montana; Mott, North Dakota; and Lethbridge, Alberta, strongly suggested that in addition to losing thousands of acres of valuable farmland to saline seeps, mineralized water was rapidly contaminating nearby reservoirs, streams, and shallow aquifers. In some cases, the water was more saline than sea water (approximately 35,000 parts per million total dissolved solids) and was unfit for domestic, livestock, and irrigation use. Reported livestock and wildlife kills in certain areas were possibly related to salinity problems.

The portion of Montana affected by saline seep is characterized by relatively thin aquifers of alluvial or glacial origin underlain by thick, virtually impervious shale formations. These shallow aquifers provide water for towns, domestic use, livestock, and are the source of numerous springs, streams, and ponds. Because ground water represents a valuable resource in this part of Montana and economic alternatives to this water supply generally do not exist, the need for a regional assessment of the saline-seep problem and related water-quality investigation became apparent. As a result, the Montana Bureau of Mines and Geology, in cooperation with the Water Quality Bureau, requested funds from the Old West Regional Commission to conduct the investigation.

METHOD OF STUDY

Because saline-seep affects domestic water supplies and because additional field personnel and analytical laboratory were available, a substantial portion of the program was subcontracted to the Water Quality Bureau, Montana Department

of Health and Environmental Sciences, Helena. The 42-county study area encompassing about 118,000 square miles (75 million acres) was divided into two general work areas with the Montana Bureau of Mines and Geology investigating northern and central Montana and the Water Quality Bureau covering the southern and eastern portion of the state.

Field information collected at each site included location, date evaluated, owner (if known), water source (stream, well, pond, etc.), water flow rate, brief site description, specific conductance, temperature, and remarks. In addition, the static water level, total depth, land surface altitude, and aquifer were also noted for wells and land surface altitude and aquifer were noted for springs. If a sample was to be sent to the lab, 4 containers of water were commonly collected--1 liter raw, 1 liter filtered ($.45\mu$), 250 ml filtered-acidified (HNO_3), and 250 ml filtered and preserved (HgCl). Biological specimens were collected in accordance with instructions outlined by Loren Bahls. Areas with extensive saline-seep development (primarily cultivated areas) were given maximum sampling effort, consequently, very few sites were evaluated in the mountains or foothills located within the study area.

The samples were analyzed by Bureau of Mines and Geology, Butte, and Water Quality Bureau, Helena, utilizing procedures adopted by the Environmental Protection Agency and the U.S. Geological Survey. Most of the samples were analyzed for major constituents (calcium, magnesium, sodium, potassium, iron, manganese, silica, carbonate, bicarbonate, chloride, sulfate, and fluoride); nutrients (nitrate, phosphate); and selected trace elements (strontium, lithium, lead, copper, zinc, nickel, and aluminum). Many of the ground-water samples were also analyzed for arsenic, boron, mercury, antimony, beryllium, cadmium, chromium, silver, selenium, and tin. Measurements for pH and lab specific conductance and calculations for dissolved solids, total hardness, alkalinity, and sodium absorption ratio were made for each sample. All chemical and pertinent field data was computerized for entry into state and federal data systems.

PROJECT OBJECTIVES

At the outset of the investigation two specific tasks or objectives were envisioned: (1) collecting and analyzing numerous surface- and ground-water samples; and (2) conducting a general water-quality survey utilizing historical data and comparing it to the new field data. As the program progressed during the first year several problems arose, and the following modifications and changes were implemented:

a) The large historical ground-water database (roughly 3,000 analyses on file at the State Board of Health) collected and analyzed from 1920 to 1970 was virtually unusable because the sample-site locations were not required or requested during this period. This reduced the usable historical data file to less than 600 analyses, few of which were located in seep-affected areas. As a result, emphasis was shifted to implement an extensive, region-wide specific conductance inventory to establish current baseline salinity levels. In all, over 2,800 wells, streams, springs, and reservoirs, and ponds, were evaluated in the field (Table 1); substantially increasing travel and personnel costs. These costs were offset by supplemental funds from the Department of State Lands saline-seep program, and by reducing the number of complete chemical analyses (Task 1).

b) Because of the absence of an extensive historical database, emphasis was placed on trying to establish and document water quality trends on existing saline-seep research sites (Fig. 2) where relatively rapid changes in water quality could be anticipated and evaluated. Specific conductance as well as water-level measurements were taken periodically (3 to 8 times per year) from each test hole and additional water quality samples were collected from selected research wells. Supplemental funds for analyses and site monitoring were obtained from the Bureau of Mines and Geology and Department of State Lands.

c) To reduce travel time of field crews and to accurately delineate significant seep-affected areas, an aerial reconnaissance survey was conducted. Seep areas were outlined on photo-index sheets (when available) and on county highway maps; they were later transferred to base maps. The aerial reconnaissance allowed field crews to concentrate on critical areas and provided the first uniformly documented distribution of saline areas in Montana.

d) Review of the chemical data obtained from selected ground-water samples collected during the first year revealed the presence of several trace elements--notably selenium, boron, tin, and aluminum--in concentrations greatly exceeding recommended limits. As a result, the suite of trace metals was expanded, increasing analytical costs significantly. Additional funds were obtained from the Bureau of Mines and Geology and Department of State Lands to offset the increased analytical costs.

e) Preliminary evaluation of several ponds indicated that in addition to the high concentrations and array of dissolved constituents and nutrients that are known to be present, there may be blue-green algae that are lethal to livestock. To investigate the potential toxic species of algae, a small subcontract was given to Dr. Loren Bahls who examined and described the benthic algae at approximately 100 different sites in the project area.

With the implementation of these changes the overall project objectives were increased from two to five:

1. To compare saline-seep formation at selected research sites with varying agronomic, geologic, and climatic conditions.
2. To assess regional extent of saline areas from aerial reconnaissance.
3. To document algal species present in selected streams and reservoirs.
4. To collect and analyze numerous water samples (Task 1 - reduced somewhat).
5. To conduct a regional water-quality (specific conductance) survey (Task 2 - greatly expanded).

COMPARISON OF SALINE-SEEP FORMATION IN GREAT PLAINS REGION

Because several papers that discuss the cause, formation, and development of saline seep in the northern Great Plains have appeared elsewhere in the literature (1, 6, 8, 9, 10, 11, 12), only a brief summary of saline-seep formation will be included in this report.

Saline seeps--defined as recently developed saline soils in non-irrigated areas that are wet some or all of the time, often with white salt crusts and

where crops or grass production are reduced or eliminated--are caused by land-use changes that allow an increased amount of moisture to migrate beneath the root zone, thereby disrupting the natural plant-soil-moisture regime. The major land-use change throughout the Great Plains Region is the alternate crop-fallow (summer fallow) farming system. Other factors that help aggravate the occurrence and spread of saline seep are:

(1) Soil, subsoil, and underlying geologic formations that contain a nearly inexhaustible supply of water-soluble salts.

(2) A climate in which a large percentage of annual precipitation occurs during the spring (April, May, and early June) before crops can utilize stored moisture effectively and before evapotranspiration is significant.

(3) Numerous poorly drained upland "potholes" (typical of glaciated terranes) that are routinely cultivated. Once the shallow clay pan at the base of the pothole has been disturbed, water readily enters the underlying substratum.

(4) A virtually impermeable material (shale or clay) beneath the soil profile that effectively impedes the downward movement of water, thus forming a "perched" or near-surface body of water. Such a condition retards or prevents drainage.

(5) Development of a local ground-water flow system that allows saline ground water to migrate from upland recharge areas toward nearby discharge (saline seep) areas.

The generalized process of saline-seep formation is shown in Figure 1. The process starts by movement of water beneath the root zone but above the shallow impermeable layers, thereby forming a local ground-water flow system. The flow system moves saline water downslope to the discharge area (seep), where it evaporates, depositing the salt on the surface.

The rocks underlying the northern and eastern parts of Montana are mostly shale, siltstone, and sandstone with some widespread deposits of glacial till. The shale and till contain relatively large amounts of soluble salts that can be readily dissolved and transported by soil moisture and ground water. The salts can remain in solution underground or can be precipitated by evaporation where the water approaches or reaches the land surface. As long as a natural

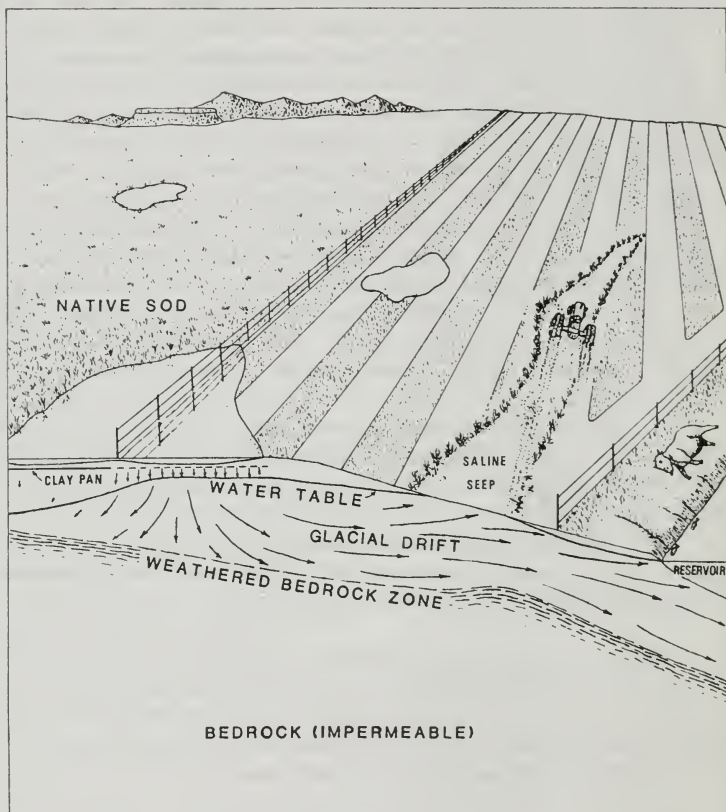


Figure 1. Generalized diagram illustrating the formation of saline seep

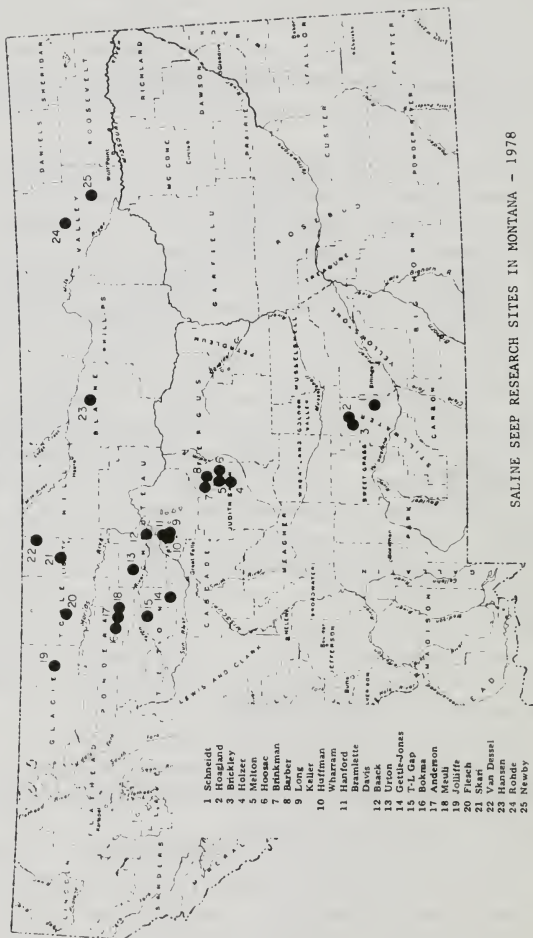
hydrologic system remains in equilibrium, salt deposition tends to remain low because of leaching during long periods of normal ground-water movement and because of the relatively small volume of water that moves through the salt-containing zones. Increased water movement from greater recharge upsets the equilibrium and causes additional salt to be dissolved and flushed.

In the Fort Union Formation, dense shale or underclay beneath coal seams impedes downward movement of water, thus forcing the water to move laterally along the coal seams until it comes to the surface in low areas. Alternate crop-fallow (summer fallow) farming system tends to build soil and subsoil moisture to the point where moisture is not completely utilized by crops, this increases the amount of water that reaches the land surface and evaporates.

During the period 1969 to 1975, the hydrogeology of 25 research sites in 12 counties have been investigated (Fig. 2). Over 550 test holes have been drilled and logged, water samples collected from selected holes, infiltration tests conducted, and repeated water-level and specific conductance measurements taken. Evaluation of this information together with data provided by other investigations in Montana, the Dakotas, and Canada (1, 4, 6, 8, 11, 12) provided a framework for a number of comparisons:

1. The alternate crop-fallow (summer fallow) farming system has been extensively utilized for at least 30 years throughout the northern Great Plains thus, providing the mechanism for regional saline-seep development.
2. The formation and development of saline seeps are the result of local ground-water flow systems. Distances from recharge areas to discharge (seep) areas are typically less than 2,500 feet.
3. The concentration of water-soluble salts contained in the soil profile and underlying substratum is quite variable but is usually high throughout the region. Some of the highest salt concentrations appear to be in northcentral (triangle area) Montana.
4. The chemical composition of saline-seep water is remarkably uniform. During the evolution of a typical saline seep, the ground-water quality changes from calcium bicarbonate type of water with relatively low Total Dissolved Solids (1,500 to 3,000 milligrams per liter) to a sodium-magnesium sulfate type of water with high Total Dissolved Solids (4,000 to 60,000

Figure 2



SALINE SEEP RESEARCH SITES IN MONTANA - 1978

milligrams per liter). In addition to the high Total Dissolved Solids (TDS) saline-seep water commonly contains much higher concentrations of nitrates and trace metals (1, 5, 6).

5. Because of the low chloride concentration in saline-seep water, seep water can be readily distinguished from deep subsurface brines.

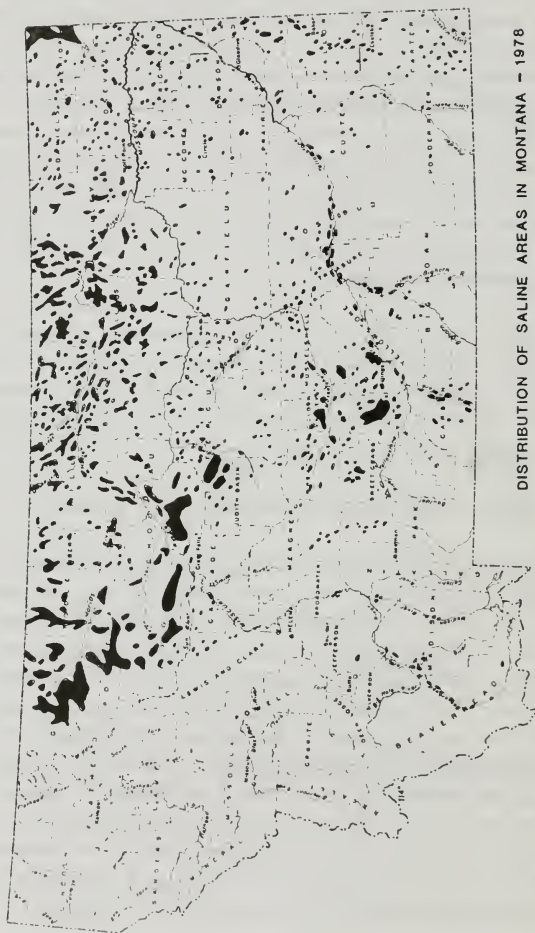
6. Intensive cropping, rotating in deep-rooted perennial crops, such as alfalfa, has been effective in stabilizing and, in some cases, reducing the size of the seep-affected area (2, 3, 4, 8). A five-year stand of alfalfa planted on one research site south of Fort Benton lowered the water table an average of 8 feet over the entire site and a 10 to 15 percent reduction in ground-water salinity has occurred.

Based on available data gathered from site-specific research test areas, it appears that specific conductance (approximation of Total Dissolved Solids) coupled with scattered chemical analyses provides useful and effective tools to assess the effect of saline seep on shallow ground-water resources and to establish regional water-quality trends.

REGIONAL EXTENT OF SALINE-SEEP DEVELOPMENT IN MONTANA

In the late 40's and early 50's a few scattered saline seeps were noted in Montana and western Canada. Since then, areas of saline seep have increased rapidly. Recent surveys (13) indicate that saline seeps have taken roughly 200,000 acres of Montana's dryland from agricultural production and that an area of roughly 2 million acres is now out of production in the Great Plains Region (Montana, North and South Dakota, Alberta, Saskatchewan, and Manitoba). The general distribution of areas in Montana that are seriously affected by salinity is shown on Fig. 3; the map is based on an aerial and field reconnaissance survey completed in 1977. Careful evaluation of the map and previous estimates suggest that the 200,000-acre figure may be somewhat low. Seep-affected areas in northern and central Montana appear to be considerably greater than previously estimated and conversely, in southern and eastern Montana the seep-affected areas appeared to be less than previous estimates.

Figure 3



DISTRIBUTION OF SALINE AREAS IN MONTANA - 1978

MONTANA BUREAU OF MINES AND GEOLOGY

An example illustrating saline-seep development over a 30-year period (1941-1971) in a 4-square mile area near Fort Benton, Montana, is shown in Fig. 4. On a region-wide basis, the acreage of saline seep appears to be expanding at an average rate exceeding 10 percent per year. The rate varies from year to year depending upon climate, but the general trend is toward significant increase. Expansion of seep areas by 20 to 200 percent in wet years is not uncommon, whereas expansion of only a few percent may occur in dry years.

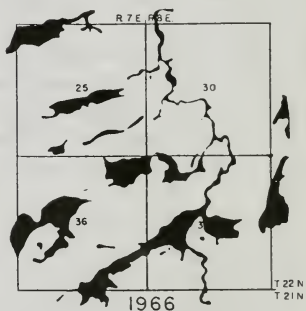
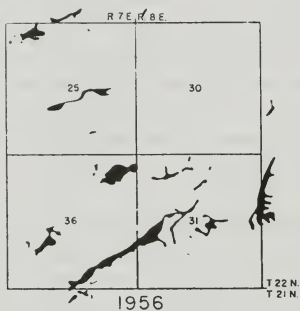
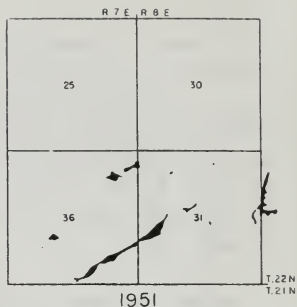
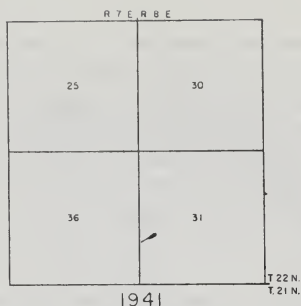
Research indicates that fallow areas can undergo a water-table rise of 1 to 15 feet during years of average or above-average spring precipitation. The water levels gradually decline during the rest of the year but normally do not reach the low of the previous year. As a result, excess water accumulates through the years, causing expansion of the saline seeps during each succeeding wet cycle. Currently, seep development is especially rapid in areas where glacial till is less than 50 feet thick. Excess water is probably building up also in extensive areas underlain by greater thicknesses of till, but as yet the buildup is not evident at the surface.

Geological conditions favoring saline-seep development extend over vast areas of Montana, the Dakotas, and the three prairie provinces of Canada. These plains are the major grain-growing regions of North America, and the cropping system is dominantly an alternate crop-fallow rotation system. As long as all factors contributing to salinization continue, the situation can only worsen.

ALGAL SURVEY OF SELECTED STREAMS AND RESERVOIRS

As previously mentioned, 100 biological specimens were collected from scattered streams and ponds in eastern Montana and the results of this algal survey are discussed in detail in the last section of this report. Significant findings specifically related to the saline-seep problems are:

1. Potentially toxic blue-green algae were present in 25 percent of the samples analyzed and were found in water with Total Dissolved Solids varying from 368 to 23,819 milligrams per liter.



0 1 MILE

Figure 4. Saline-seep development over a 30-year period on a 4-square mile area near Ft. Benton, Montana.

2. Diatom diversity was significant and was related inversely to specific conductance.

WATER QUALITY AND SPECIFIC CONDUCTANCE SURVEY OF THE MONTANA PLAINS

Data collected to fulfill specific Tasks 1 and 2 are presented in the following section. For uniformity of presentation and to better show the distribution of sample sites, the data was not plotted on county base maps but on 1° x 2° Army Map service maps with a scale of 1/4 inch equals one mile.

Eighteen 1° x 2° maps, each covering about 6,900 square miles, were needed to encompass the Montana plains. The 1° x 2° maps on open file at Montana Bureau of Mines and Geology (MBMG) are arranged in alphabetical order instead of geographical order. The 1° x 2° sheets include: Billings, Bozeman, Choteau, Cut Bank, Ekalaka, Forsyth, Glasgow, Glendive, Great Falls, Hardin, Havre, Jordan, Lewistown, Miles City, Roundup, Shelby, White Sulphur Springs, and Wolf Point. Each 1° x 2° map is subdivided into eight 30 minute by 30 minute page-sized sheets. The arrangement of the sheets is shown on the Location Base Map sheet that precedes each 1° x 2° map section.

Each site evaluated was carefully located using the site location system (Township, Range, Section, and Tract) described on pages 21 and 22 (Appendix A). Hopefully many of these sites can be re-evaluated in the future to document changes and to quantify water quality trends.

The several types of symbols used on the specific conductance survey maps refers to the sample source (spring, well, pond, etc.). The legend for these symbols is given on page 23 (Appendix B). Two numbers generally accompany each symbol. The number in parenthesis is the map reference number. This number is repeated in the Specific Conductivity Inventory section where additional information about the site may be found. The map reference number also will be found in the Chemical Analyses of Selected Waters and Trace Elements Analyses sections if a water sample from that site was chemically analysed. The other number generally included with each symbol is the specific conductance (corrected to 25°C) of water from that site.

This information (1° x 2° maps, Specific Conductivity Inventory Sheets, Standard Chemical Analyses Tables and Trace Element Analyses Listings) is on open file (MBMG Open File Report 42) at the Montana Bureau of Mines and Geology and can be obtained for the cost of duplication.

Specific conductance (SC) is a measurement of the waters capacity to conduct an electric current. Because it varies directly with both temperature and the overall salinity of the water, all values are converted to 25 degrees Celsius making salinity the only variable. When the SC is measured in micromhos per centimeter, it roughly equals the Total Dissolved Solids (TDS) content in milligrams per liter (mg/l). The general relationships between SC and TDS is illustrated in Fig. 5. Note that when TDS is less than 8,000 mg/l the SC is about 1.05 to 1.10 times TDS, they are about equal when TDS is between 8,000 and 12,000 mg/l, and when the TDS is greater than 12,000 mg/l the SC is about 0.70 to 0.95 times TDS.

Part of the project to investigate regional aspects of water quality necessitated identification of water source by aquifer. This was to help determine if water from some aquifers yielded water more suitable for human and livestock consumption and also to see if water quality changed regionally within that aquifer. The aquifer code is thus included with many sample sites. The explanation for the aquifer code will be found on pages 23 and 24.

A summary of the regional saline-seep assessment by AMS 1° x 2° sheets is tabulated in Table 1. During the project 2,876 sites were evaluated in the field, 452 water samples were collected with 247 of these analysed for trace elements. Of the 2,800 plus sites, 14 percent has SC values less than 500; 16 percent between 500 and 1,000, 64 percent between 1,000 and 10,000; and 6 percent over 10,000 micromhos per centimeter. Because of the above-average precipitation during the 2-year period of the project, the reported SC values obtained from all the surface-water sites (about 50%) were undoubtedly low. Conductivity and trace-metal concentrations were considerably higher in wells penetrating the glacial and Cretaceous marine aquifers (northern and central Montana) than in the non-marine late Cretaceous and Tertiary aquifers. Chemical composition of ground water collected in glaciated portions of Montana were predominantly the sodium-magnesium sulfate type--similar to water collected from research test holes.

Significant concentrations of trace elements particularly selenium and boron, were found in many of the ground-water samples. Of the 160 samples

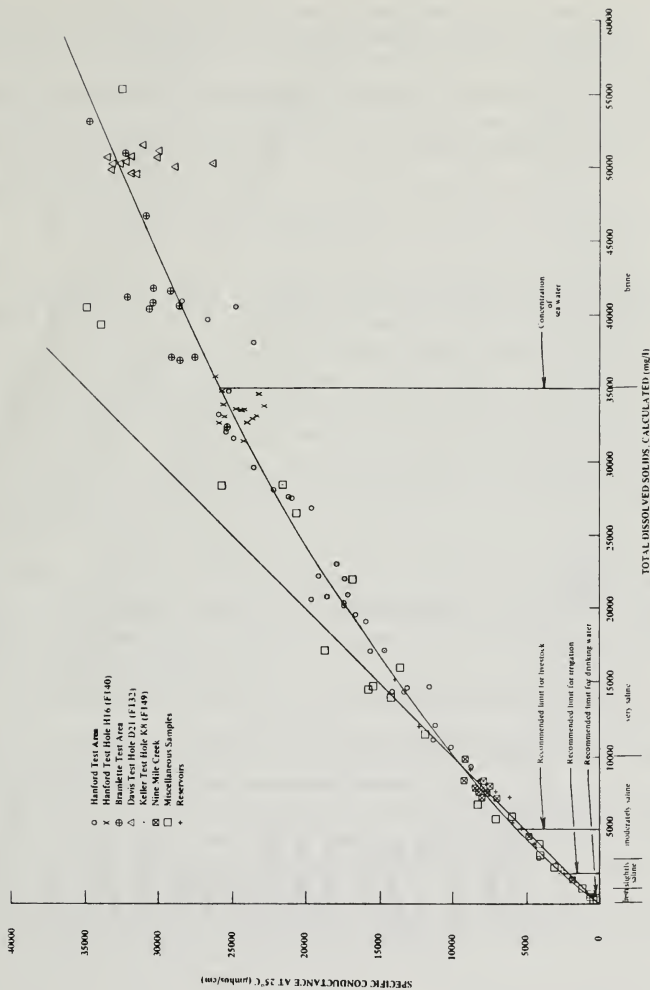


Figure 5.—Comparison between total dissolved solids and specific conductance of water samples from Highwood Bench area.

Table 1

| SUMMARY OF SALINE SEEP ASSESSMENT RESULTS | | | | | | | | | |
|---|---------------------------|-----------------------------|----------------------------------|--------------------------|-------------------------------|----------------------------------|------------------------------------|---------------------------------|-------------------------|
| | NUMBER OF SITES EVALUATED | NUMBER OF CHEMICAL ANALYSES | NUMBER OF ANALYSES COLL. 75-'78' | NUMBER OF TRACE ANALYSES | NUMBER OF SITES WITH SC < 500 | NUMBER OF SITES WITH SC 500-1000 | NUMBER OF SITES WITH SC 1000-10000 | NUMBER OF SITES WITH SC > 10000 | NUMBER OF ALGAL SAMPLES |
| AMS 10x 20-sheet | 149 | 73 | 54 | 24 | 9 | 16 | 81 | 28 | 15 |
| BILLINGS | | | | | | | | | |
| BOZEMAN | 18 | 5 | 5 | 0 | 11 | 5 | 2 | 0 | 0 |
| CHOTEAU | 66 | 11 | 11 | 5 | 22 | 21 | 22 | 1 | 2 |
| CUT BANK | 180 | 103 | 28 | 20 | 16 | 17 | 78 | 1 | 0 |
| EKALAKA | 26 | 14 | 11 | 0 | 0 | 0 | 26 | 0 | 0 |
| FORSYTH | 72 | 44 | 13 | 6 | 5 | 6 | 45 | 11 | 0 |
| GLASGOW | 194 | 29 | 21 | 21 | 17 | 44 | 120 | 2 | 7 |
| GLENDIVE | 132 | 54 | 37 | 20 | 6 | 8 | 95 | 14 | 6 |
| GREAT FALLS | 261 | 37 | 35 | 35 | 46 | 65 | 130 | 14 | 7 |
| HARDIN | 231 | 220 | 32 | 22 | 2 | 19 | 192 | 3 | 1 |
| HAVRE | 305 | 42 | 18 | 17 | 76 | 49 | 166 | 2 | 8 |
| JORDAN | 73 | 11 | 5 | 2 | 8 | 4 | 52 | 4 | 5 |
| LEWISTOWN | 195 | 46 | 18 | 18 | 25 | 33 | 102 | 6 | 21 |
| MILES CITY | 90 | 31 | 13 | 1 | 4 | 5 | 61 | 15 | 0 |
| ROUNDUP | 207 | 64 | 27 | 12 | 24 | 48 | 106 | 7 | 9 |
| SHELBY | 367 | 60 | 57 | 42 | 65 | 31 | 242 | 15 | 3 |
| WHITE SUL. SPRINGS | 51 | 11 | 7 | 0 | 21 | 16 | 12 | 1 | 0 |
| WOLF POINT | 259 | 168 | 60 | 2 | 19 | 32 | 155 | 40 | 16 |
| TOTAL | 2876 | 1023 | 452 | 247 | 376 | 419 | 1687 | 164 | 100 |

analysed for selenium over 30 percent had concentrations greater than 10 micrograms per liter ($\mu\text{g/l}$). Analyses of water collected from aquifers associated with the Colorado Shale, which is known to be seleniferous, showed that 59 percent of the water samples contained more than the 10 $\mu\text{g/l}$ limit for potable water set by U.S. Public Health Service; some values were as high as 1,800 $\mu\text{g/l}$. Many of these wells are being used for domestic or stock watering purposes.

CONCLUSIONS

Because of the lack of a detailed historical database, it is difficult to quantify the effects of saline-seep development on the surface water and shallow ground-water resources of the area, however, presently available data suggest that significant water-quality deterioration has occurred in the glaciated portion of Montana where dryland farming has been a way-of-life for many years. Several other areas of concern are in Judith Basin, Fergus, and Stillwater counties where saline seep is spreading rapidly. Undoubtedly, many other areas have local problems, but our sampling base was not dense enough to delineate them.

Numerous discussions with county agents, district conservationist, and rural leaders typically support the above statements, and probably the most convincing statements came from the landowners. Some of the more frequent statements made by farmers are:

- a) "Our well(or wells)went bad and we have been hauling water for years".
- b) "Over the last 5 (to 20) years we have had to drill 2 (to 4) wells, each one deeper than the last to get good water".
- c) "Three (to 5) years ago our well turned bad during the spring, and each year we have to haul water for a longer period of time".
- d) "All the wells in the area have gone bad, that is why we hooked up to the rural water distribution system".
- e) "During the last 5 (to 15) years, springs have appeared in several coulees and now the banks are sliding into the draw".
- f) "The cows will drink from the reservoir only during the spring of the year".

g) "My reservoir used to be the best fishing in these parts, but the fish all died 1 (to 10) years ago".

h) "I don't have any freshwater left on my place, so I guess I'll sell all my cattle and plow-up the rest of my pasture".

i) "Over the last 2 (to 10) years I have had to pump out by basement each spring, and it seems to be getting worse".

j) "Last year my shelter-belt began to die".

All of these statements, and many more, imply that the local ground-water flow system is out of equilibrium, flushing the salts out of the profile, and rapidly contaminating the water resources of the area.

RECOMMENDATIONS

1. Immediately intensify cropping practices over the entire northern plains region to hopefully get the problem stabilized.
2. Rotate deep-rooted legumes such as alfalfa into the cropping system, particularly on recharge areas.
3. Surface drainage of upland, freshwater potholes that are normally cultivated should be encouraged. Research on all drainage systems particularly subsurface drains, should be initiated to determine the long- and short-term benefits, if any.
4. Maintain an active and comprehensive monitoring and sampling network throughout the region to use for forecasting ground-water conditions in a given area; to quantify long- and short-term changes in water quality; and to evaluate the effectiveness of various cropping systems in controlling saline-seep formation (demonstration- and research-site programs).
5. Initiate research on the distribution, behavior, and potential for toxicity of selected trace elements in ground water of the northern Great Plains--immediate attention should be given to selenium.
6. Maintain and add water-quality information to data-systems to document and quantify future changes and trends. A follow-up regional inventory in 5 to 8 years utilizing many of the wells evaluated in the present study would be particularly valuable in achieving this objective.
7. Encourage and promote a coordinated research, education, and extension program to hopefully get control of the saline-seep problem in the shortest amount of time.

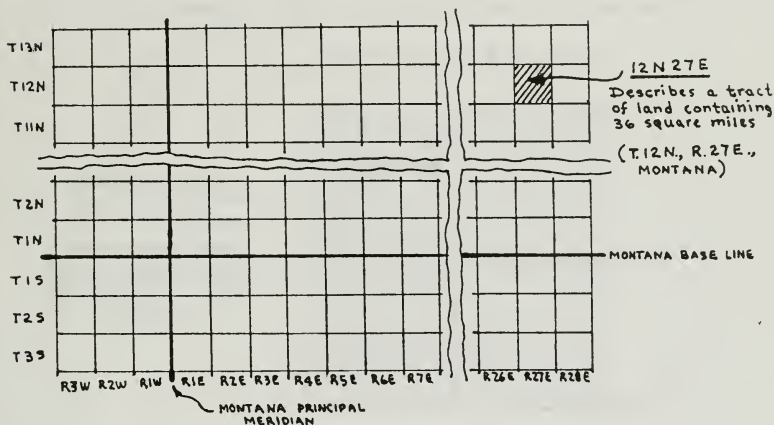
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SITE LOCATION SYSTEM

The location of objects in Montana (such as wells, springs, ponds, etc.) is referenced to the legal subdivisions of public lands--that is--by Township, Range, Section, and Quarters of a section. Thus a site description of 12 N 27E designates a particular township, 6 miles on a side, that lies 12 townships north of the the Montana Base Line and 27 townships east of the Montana Principal Meridian.



Each township is subdivided into 36 sections as follows:

Subdivision of T.12N., R.27E.

| | | | | | |
|----|----|----|----|----|----|
| 6 | 5 | 4 | 3 | 2 | 1 |
| 7 | 8 | 9 | 10 | 11 | 12 |
| 18 | 17 | 16 | 15 | 14 | 13 |
| 19 | 20 | 21 | 22 | 23 | 24 |
| 30 | 29 | 28 | 27 | 26 | 25 |
| 31 | 32 | 33 | 34 | 35 | 36 |

12N 27E15

Describes a tract of land 1 mile square
(section 15, T.12N., R.27E., MONTANA)

The subdivision of a particular section into quarters, however, departs from legal usage in that the letters A, B, C, and D are used for the NE $\frac{1}{4}$, NW $\frac{1}{4}$, SW $\frac{1}{4}$, and SE $\frac{1}{4}$ respectively. Additionally the quartering of a section in the Site Location System begins with the largest quarter (the 160-acre tract) then proceeds to the 40-acre tract, the 10-acre tract, and the 2.5-acre tract. If, for example, a well site is described as 12N 27E 15 ABCD, the location of that well is in the SE $\frac{1}{4}$, SW $\frac{1}{4}$, NW $\frac{1}{4}$ of the NE $\frac{1}{4}$, Section 15, Township 12N, Range 27E. In the sequence ABCD, the 1st letter (A) describes the NE $\frac{1}{4}$, the 2nd letter (B) calls out the NW $\frac{1}{4}$ of the NE $\frac{1}{4}$, the 3rd letter (C) calls out the SW $\frac{1}{4}$ of the NW $\frac{1}{4}$ of the NE $\frac{1}{4}$, and the 4th letter (D) calls out the SE $\frac{1}{4}$ of the SW $\frac{1}{4}$ of the NW $\frac{1}{4}$ of the NE $\frac{1}{4}$.

Each section is subdivided into quarters as follows:

Subdivision of Sec. 15, T. 12N., R. 27E.

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| B | A | B | A | B | A | B | A | B | A | B | A | B | A | B | A |
| C | D | C | D | C | D | C | D | C | D | C | D | C | D | C | D |
| B | A | B | A | B | A | B | A | B | A | B | A | B | A | B | A |
| C | D | C | D | C | D | C | D | C | D | C | D | C | D | C | D |
| B | A | B | A | B | A | B | A | B | A | B | A | B | A | B | A |
| C | D | C | D | C | D | C | D | C | D | C | D | C | D | C | D |
| B | A | B | A | B | A | B | A | B | A | B | A | B | A | B | A |
| C | D | C | D | C | D | C | D | C | D | C | D | C | D | C | D |
| B | A | B | A | B | A | B | A | B | A | B | A | B | A | B | A |
| C | D | C | D | C | D | C | D | C | D | C | D | C | D | C | D |
| B | A | B | A | B | A | B | A | B | A | B | A | B | A | B | A |
| C | D | C | D | C | D | C | D | C | D | C | D | C | D | C | D |
| B | A | B | A | B | A | B | A | B | A | B | A | B | A | B | A |
| C | D | C | D | C | D | C | D | C | D | C | D | C | D | C | D |
| B | A | B | A | B | A | B | A | B | A | B | A | B | A | B | A |
| C | D | C | D | C | D | C | D | C | D | C | D | C | D | C | D |

12N 27E 15 ABCD













Describes a tract of land
containing 2.5 acres

(the SE $\frac{1}{4}$ SW $\frac{1}{4}$ NW $\frac{1}{4}$ NE $\frac{1}{4}$,
Sec. 15, T. 12 N., R. 27 E.,
MONTANA)

If more than one object is being described in a particular 2.5-acre tract, sequence numbers 1, 2, 3 . . . etc. are given to those objects to distinguish them. Thus 12N 27E 15 ABCD₂ refers to object 2 in the SE $\frac{1}{4}$ SW $\frac{1}{4}$ NW $\frac{1}{4}$ NE $\frac{1}{4}$ section 15, Township 12 North, Range 27 East, Montana.

Appendix B

LEGEND FOR MAP SYMBOLS

| | | |
|--|---|----------------------|
|  |  | creek, river, stream |
|  |  | ditch, drain |
|  |  | seep |
|  |  | lake, pond, marsh |
|  |  | well |
|  |  | spring |

Solid symbols indicate that a chemical analysis is available

LEGEND FOR AQUIFER CODE

| <u>CODE</u> | <u>AGE</u> | <u>FORMATION</u> |
|-------------|-------------|------------------------|
| 110ALVM | Quaternary | Alluvium |
| 110CLVM | Quaternary | Colluvium |
| 110TRRC | Quaternary | Terrace deposits |
| 112DRFT | Pleistocene | Glacial drift |
| 112GCLO | Pleistocene | Glacial outwash |
| 112GLCC | Pleistocene | Glacial lake deposits |
| 1120TSH | Pleistocene | Outwash |
| 112TILL | Pleistocene | Glacial till |
| 112TRRC | Pleistocene | Terrace deposits |
| 121FLXV | Pliocene | Flaxville Formation |
| 125FRUN | Paleocene | Fort Union Formation |
| 125TGRV | Paleocene | Tongue River Member |
| 125TLCK | Paleocene | Tullock Member |
| 210CLRD | See 211CLRD | |
| 211BRPW | Cretaceous | Bearpaw Shale |
| 211CLGT | Cretaceous | Claggett Shale |
| 211CLRD | Cretaceous | Colorado Group |
| 211EGLE | Cretaceous | Eagle Sandstone |
| 211FRNR | Cretaceous | Frontier Formation |
| 211FXHL | Cretaceous | Fox Hills Formation |
| 211HLCK | Cretaceous | Hell Creek Formation |
| 211JDRV | Cretaceous | Judith River Formation |
| 211MRSN | See 221MRSN | |

| <u>CODE</u> | <u>AGE</u> | <u>FORMATION</u> |
|-------------|---------------|----------------------------|
| 211MSBY | Cretaceous | Mosby Sandstone |
| 211TMDC | Cretaceous | Two Medicine Formation |
| 211TPCK | Cretaceous | Telegraph Creek Formation |
| 211VLCC | Cretaceous | Volcanic rocks |
| 211VRGL | Cretaceous | Virgille Sandstone |
| 217DKOT | Cretaceous | Dakota Sandstone |
| 217KOTN | Cretaceous | Kootenai Formation |
| 217LKOT | Cretaceous | Lakota Sandstone |
| 217MDDY | Cretaceous | Muddy Sandstone |
| 217SCCK | Cretaceous | Second Cat Creek Sandstone |
| 221MRSN | Jurassic | Morrison Formation |
| 221SWFT | Jurassic | Swift Formation |
| 224PIPR | Jurassic | Piper Formation |
| 230SPRF | Triassic | Spearfish Formation |
| 317TSLP | Permian | Tensleep Sandstone |
| 320AMSD | Pennsylvanian | Amsden Formation |
| 320TSLP | See 317TSLP | |
| 320TYLR | Pennsylvanian | Tyler Formation |
| 331CRLE | Mississippian | Charles Formation |
| 331HETH | Mississippian | Heath Formation |
| 331KBBY | Mississippian | Kibbey Formation |
| 331MDSN | Mississippian | Madison Group |
| 331MSNC | Mississippian | Mission Canyon Limestone |
| 337LDGP | Mississippian | Lodgepole Limestone |
| 337MSNC | See 331MSNC | |

